

LOSS PROCESS FOR HELIUM IONS IN THE UPPER ATMOSPHERE

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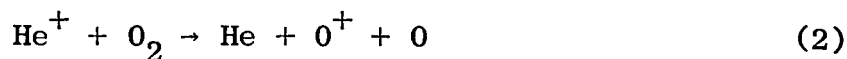
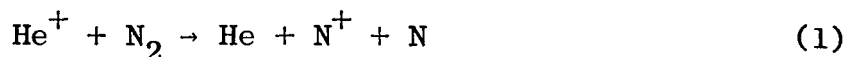
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LOSS PROCESS FOR HELIUM IONS IN THE UPPER ATMOSPHERE

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Hanson⁽¹⁾ originally suggested that upper atmospheric helium ions produced by photoionization may be lost by an ion-atom interchange process with molecular nitrogen. Bates and Patterson⁽²⁾ have argued that the loss process with N_2 is unlikely to occur since it is endothermic, but that a similar process with O_2 may well be possible which also would lead to the creation of neutral helium with energy greater than that required for escape. Thus, the latter process represents also an attractive solution to the long standing problem of helium escape. Most recently, Ferguson et al⁽³⁾ have presented evidence from laboratory measurements, that the rate coefficient for the reaction of helium ions with N_2 is about the same as that involving O_2 , both having the rather high value of $k \approx 10^{-9} \text{ cm}^3 \text{ sec}^{-1}$, so that the loss process for He^+ would obviously be governed by the more abundant constituent N_2 . Previous laboratory measurements by Fite et al⁽⁴⁾ indicated that whereas the reaction of He^+ with O_2 has a rate coefficient of the order of $5 \times 10^{-10} \text{ cm}^3 \text{ sec}^{-1}$, the reaction rate of the process involving N_2 must be much smaller.

The two possible loss processes suggested by these laboratory experiments are as follows:



since the only ionic constituents found in the laboratory reactions are N^+ and O^+ , respectively. The processes (1) and (2) would correspond to dissociative charge transfer, although

the final product of (2) does not preclude the occurrence of the ion-atom interchange process suggested by Bates and Patterson⁽²⁾.

In view of the great importance of the He^+ loss process for a number of aeronomic problems, including that of helium escape, a test of the suggestion of Ferguson et al based on the observed atmospheric ion composition data, is imperative. Unfortunately there are only a few measurements of the vertical distribution of He^+ by means of rocket-borne ion mass spectrometer^(5,6,7). Of these, the measurement by Pokhunkov⁽⁵⁾ is most suitable for such a test since it provides in addition to the altitude variation of He^+ that of the minor ion N^+ . As we shall see, the simultaneous measurement of He^+ and N^+ is important to this test. Although Pokhunkov's data extends only to an altitude of 430 km, this is sufficient for the test, since we are concerned only with the region where He^+ is controlled by chemical equilibrium⁽⁸⁾. Since the loss process is leading to the formation of N^+ , which exists in the atmosphere as a minor ionic constituent, the behavior of this ion should be useful in our test. From Pokhunkov's observation it is apparent that above 350 km N^+ decreases very slowly with altitude. This can be explained as the result of production of N^+ via the He^+ loss process (1) involving N_2 as shown in the following.

For He^+ in chemical equilibrium we can write

$$I_{\text{He}}[\text{He}] = [\text{He}^+]\{k_1[\text{N}_2] + k_2[\text{O}_2]\} \quad (3)$$

where $I_{\text{He}} = 3 \times 10^{-8} \text{sec}^{-1}$ is the photo-ionization rate coefficient for helium⁽⁹⁾ which can be used at altitudes above 300 km where the optical thickness is negligibly small. According to Ferguson et al⁽³⁾, $k_1 \approx k_2$ and since $[\text{N}_2] \gg [\text{O}_2]$ we neglect the loss term involving O_2 . Thus, the distribution of He^+ in chemical equilibrium can be expressed by

$$[\text{He}^+] = \frac{I_{\text{He}}[\text{He}]}{k_1[\text{N}_2]} \quad (4)$$

The rate of formation of N^+ , $q(\text{N}^+)$, can be written

$$q(\text{N}^+) = I_{\text{N}}[\text{N}] + k_1[\text{He}^+][\text{N}_2] \quad (5)$$

Since atomic nitrogen is a minor constituent and its photoionization rate coefficient I_{N} is comparable to $k_1[\text{He}^+]$, we shall neglect the photoionization term compared to the chemical production term. Any conceivable chemical loss process for N^+ at altitudes above 300 km will have a longer time constant than the diffusion time, so that the production rate of N^+ should be balanced by the divergence of the diffusion flux $(\frac{\partial F(\text{N}^+)}{\partial z})$; thus

$$\frac{\partial F(\text{N}^+)}{\partial z} = k_1[\text{He}^+][\text{N}_2] \quad (6)$$

It is easily shown that, neglecting second order terms, $\frac{\partial F(\text{N}^+)}{\partial z} \approx \frac{F(\text{N}^+)}{H_D}$, where H_D is the scale height of the constituent through which N^+ diffuses, i.e. the scale height of O^+ , while $F(\text{N}^+) = [\text{N}^+]v_D$, where v_D is the diffusion velocity. If we assume that $v_D = \text{const}$ over the altitude range under consideration, we can write $v_D/H_D = K$ and thus from (6):

$$[\text{N}^+] \approx \frac{k_1}{K} [\text{He}^+][\text{N}_2] \quad (7)$$

Substituting from (4) for $[\text{He}^+]$ we obtain

$$[\text{N}^+] \approx \frac{I_{\text{He}}}{K} [\text{He}] \quad (8)$$

Thus, the altitude variation of N^+ should follow that of neutral helium. This is shown in Fig. 1 where the ion concentrations

represent the smoothed data of Pokhunkov⁽⁵⁾ and the neutral constituents are based on the 1964 Harris-Priester upper atmosphere model⁽¹⁰⁾ for a temperature of $T \approx 1000^\circ\text{K}$, corresponding to the time of the rocket observation. It is also seen in Fig. 1 that He^+ follows the ratio $[\text{He}]/[\text{N}_2]$ according to (4). (Although the neutral constituents were also measured by Pokhunkov⁽¹¹⁾ on the same rocket flight, no helium was observed, because its concentration was too low to be detected by the mass spectrometer. The observed N_2 distribution, however, is in good agreement with the model distribution⁽¹⁰⁾ used here.)

While there thus appears to be good evidence that a reaction involving N_2 is responsible for the loss of He^+ as suggested by Ferguson et al⁽³⁾, their rate coefficient, however, is unacceptably high in the light of the experimental data of Pokhunkov⁽⁵⁾, as well as those of Taylor et al⁽⁶⁾. Based on realistic assumptions about the density of neutral constituents but allowing for an underestimate of $I_{\text{He}}[\text{He}]/[\text{N}_2]$ by as much as one order of magnitude, a maximum value of the rate coefficient $k_1 \leq 10^{-11} \text{cm}^3 \text{sec}^{-1}$ is acceptable in the light of atmospheric data. Furthermore, if helium ions are indeed lost primarily by process (1) involving N_2 , as suggested here, then it also follows that the rate coefficient k_2 for the loss process (2) involving O_2 must be comparable to k_1 . Thus, the laboratory values of Ferguson et al⁽⁵⁾ for k_1 and k_2 are at least two orders of magnitude higher than the maximum value consistent with atmospheric data. It should be noted that a value of $k_1 \approx 10^{-12} \text{cm}^3 \text{sec}^{-1}$ was originally inferred from the first, though indirect, observation of helium ions in the upper atmosphere⁽¹⁾.

REFERENCES

1. W. B. Hanson, J. Geophys. Res. 67, 183 (1962).
2. D. R. Bates and T. N. L. Patterson, Planet. Space Sci. 9, 599 (1962).
3. E. E. Ferguson, F. C. Fehsenfeld, D. B. Dunkin, A. L. Schmeltekopf and H. I. Schiff, Planet. Space Sci. 12, (1964) in press.
4. W. L. Fite, A. C. H. Smith, R. F. Stebbings and J. A. Rutherford, J. Geophys. Res. 68, 3225, (1963).
5. A. A. Pokhunkov, Kosmich.Issled., (Cosmic Research), 1, 267 (1963).
6. H. A. Taylor, L. H. Brace, H. C. Brinton and C. R. Smith, J. Geophys. Res., 68, 5339 (1963).
7. J. H. Hoffman, Naval Research Laboratory, private communication (1964).
8. S. J. Bauer, J. Geophys. Res., 69, 553, (1964).
9. H. E. Hinteregger and K. Watanabe, J. Geophys. Res., 67, 3373 (1962).
10. I. Harris and W. Priester, The Upper Atmosphere in the Range from 120 to 800 km, NASA Institute for Space Studies, New York, 1964.
11. A. A. Pokhunkov, Kosmich.Issled., (Cosmic Research) 1, 147 (1963).

CAPTION FOR FIG. 1

Altitude variation of observed ionic constituents and related neutral constituents from model atmosphere. Solid line curves represent the smoothed (within error limits) ion concentration data of Pokhunkov⁽⁵⁾, dashed lines are neutral constituents from Harris-Priester model atmosphere⁽¹⁰⁾ for $T \approx 1000^\circ\text{K}$, corresponding to the time of ion concentration measurement (15 November 1961, 1600 LMT).

